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The action of sulphuric ether upon blood differs in many respects from that of chloroform. In the first place, ether has a powerful effect in destroying the blood-corpuscles, dissolving the cell-walls' and setting the contents free. In the second place, ether prevents the blood from assuming an arterial tint when agitated with air. The higher the percentage of the agent, the more marked the effect. In the third place, ether neither diminishes the absorption of oxygen nor the exhalation of carbonic acid by blood ; and lastly, it has a much more powerful effect in causing the constituents of the blood to crystallize. For example, if an equal part of ether be added to the blood of a dog poisoned by the inhalation of chloroform, as the ether evaporates groups of large needle-shaped crystals are formed. Under the microscope the crystals are found to be of a red colour and prismatic shape.

Alcohol acts upon blood somewhat like chloroform ; it arrests the chemical changes, but in a less marked degree.

Amylene was found to act like ether upon blood, in so far as it did not diminish the absorption of oxygen or retard the elimination of carbonic acid. It differed, however, from ether in not destroying the blood-corpuscles.

In the last place, the action of mineral substances is stated, viz. :—

1. Corrosive sublimate was found to increase the chemical changes which develope carbonic acid, and to have scarcely any effect on those depending upon oxidation ; its influence, if any, is rather to diminish them than otherwise.

2. Arsenic seems to retard both the oxidation of the constituents of the blood and the exhalation of carbonic acid.

3. Tartrate of antimony increases the exhalation of carbonic acid gas, while it at the same time diminishes the absorption of oxygen.

4. Sulphate of zinc and sulphate of copper both act like tartrate of antimony, but not nearly so powerfully.

Lastly, phosphoric acid was found to have the effect of increasing the chemical transformations and decompositions upon which the exhalation of carbonic acid depends.

*March 17, 1864.*

Major-General SABINE, President, in the Chair.

The following communications were read :—

- I. “ Researches on Radiant Heat.—Fifth Memoir. Contributions to Molecular Physics.” By J. TYNDALL, F.R.S., &c. Received March 17, 1864.

(Abstract.)

Considered broadly, two substances, or two forms of substance, occupy universe—the ordinary and tangible matter of that universe, and the

intangible and mysterious ether in which that matter is immersed. The natural philosophy of the future must mainly consist in the examination of the relations of these two substances. The hope of being able to come closer to the origin of the ethereal waves, to get some experimental hold of the molecules whence issue the undulations of light and heat, has stimulated the author in the labours which have occupied him for the last five years, and it is this hope, rather than the desire to multiply the facts already known regarding the action of radiant heat, which prompted his present investigation.

He had already shown the enormous differences which exist between gaseous bodies, as regards both their power of absorbing and emitting radiant heat. When a gas is condensed to a liquid, or a liquid congealed to a solid, the molecules coalesce, and grapple with each other, by forces which were insensible as long as the gaseous state was maintained. But though the molecules are thus drawn together, the ether still surrounds them: hence, if the acts of radiation and absorption depend on the individual molecules, they will assert their power even after their state of aggregation has been changed. If, on the contrary, their mutual entanglement by the force of cohesion be of paramount influence in the interception and emission of radiant heat, then we may expect that liquids will exhibit a deportment towards radiant heat altogether different from that of the vapour from which they are derived.

The first part of the present inquiry is devoted to an exhaustive examination of this question. The author employed twelve different liquids, and operated upon five different layers of each, which varied in thickness from 0·02 of an inch to 0·27 of an inch. The liquids were enclosed, not in glass vessels, which would have materially modified the heat, but between plates of transparent rock-salt, which but slightly affected the radiation. His source of heat throughout these comparative experiments consisted of a spiral of platinum wire, raised to incandescence by an electric current of unvarying strength. The quantities of radiant heat absorbed and transmitted by each of the liquids at the respective thicknesses were first determined; the vapours of these liquids were subsequently examined, the quantities of vapour employed being proportional to the quantities of liquid traversed by the radiant heat. The result of the comparison was that, for heat of the same quality, the order of absorption of liquids and that of their vapours are identical. There was no exception to this law; so that, to determine the position of a vapour as an absorber or radiator, it is only necessary to determine the position of its liquid.

This result proves that the state of aggregation, as far, at all events, as the liquid stage is concerned, is of altogether subordinate moment—a conclusion which will probably prove to be of cardinal moment in molecular physics. On one important and contested point it has a special bearing. If the position of a liquid as an absorber and radiator determine that of its

vapour, the position of water fixes that of aqueous vapour. Water had been compared with other liquids in a multitude of experiments, and it was found that as a radiant and as an absorbent it transcends them all. Thus, for example, a layer of bisulphide of carbon, 0·02 of an inch in thickness, absorbs 6 per cent., and allows 94 per cent. of the radiation from the red-hot platinum spiral to pass through it ; benzol absorbs 43, and transmits 57 per cent. of the same radiation ; alcohol absorbs 67, and transmits 33 per cent., and it stands at the head of all liquids except one in point of power as an absorber. The exception is *water*. A layer of this substance, of the thickness above given, absorbs 81 per cent., and permits only 19 per cent. of the radiation to pass through it. Had no single experiment ever been made upon the *vapour* of water, we might infer with certainty from the deportment of the *liquid*, that weight for weight this vapour transcends all others in its power of absorbing and emitting radiant heat.

The relation of absorption and radiation to the chemical constitution of the radiant and absorbent substances was next briefly considered.

For the first six substances in the list of those examined, the radiant and absorbent powers augment as the number of atoms in the compound molecule augments. Thus, bisulphide of carbon has 3 atoms, chloroform 5, iodide of ethyl 8, benzol 12, and amylene 15 atoms in their respective molecules ; and the order of their powers as radiants and absorbents is that here indicated—bisulphide of carbon being the feeblest, and amylene the strongest of the six. Alcohol, however, excels benzol as an absorber, though it has but 9 atoms in its molecule ; but, on the other hand, its molecule is rendered more *complex* than that of benzol by the introduction of a new element. Benzol contains carbon and hydrogen, while alcohol contains carbon, hydrogen, and oxygen. Thus, not only does the idea of *multitude* come into play in absorption and radiation, that of *complexity* must also be taken into account. The author directed the particular attention of chemists to the molecule of water ; the deportment of this substance towards radiant heat being perfectly anomalous, if the chemical formula at present ascribed to it be correct.

Sir William Herschel made the important discovery that beyond the limits of the red end of the solar spectrum, rays of high heating power exist which are incompetent to excite vision. The author has examined the deportment of those rays towards certain bodies which are perfectly opaque to light. Dissolving iodine in the bisulphide of carbon, he obtained a solution which entirely intercepted the light of the most brilliant flames, while to the extra-red rays of the spectrum the same iodine was found to be perfectly diathermic. The transparent bisulphide, which is highly pervious to the heat here employed, exercised the same absorption as the opaque solution. A hollow prism filled with the opaque liquid was placed in the path of the beam from an electric lamp ; the light-spectrum was completely intercepted, but the heat-spectrum was received upon a

screen, and could be there examined. Falling upon a thermo-electric pile, its presence was shown by the prompt deflection of even a coarse galvanometer.

What, then, is the physical meaning of opacity and transparency, as regards light and radiant heat? The luminous rays of the spectrum differ from the non-luminous ones simply in *period*. The sensation of light is excited by waves of ether shorter and more quickly recurrent than those which fall beyond the extreme red. But why should iodine stop the former, and allow the latter to pass? The answer to this question, no doubt, is, that the intercepted waves are those whose periods of recurrence coincide with the periods of oscillation possible to the atoms of the dissolved iodine. The elastic forces which separate these atoms are such as to compel them to vibrate in definite periods, and when these periods synchronize with those of the ethereal waves the latter are absorbed. Briefly defined, their transparency in liquids, as well as in gases, is synonymous with *discord*, while opacity is synonymous with *accord* between the periods of the waves of ether and those of the molecules of the body on which they impinge. All ordinary transparent and colourless substances owe their transparency to the discord which exists between the oscillating periods of their molecules and those of the waves of the whole visible spectrum. The general discord of the vibrating periods of the molecules of compound bodies with the light-giving waves of the spectrum may be inferred from the prevalence of the property of transparency in compounds, solid, liquid, and gaseous, while their greater harmony with the extra-red periods is to be inferred from their opacity to the extra-red rays.

Water illustrates this transparency and opacity in the most striking manner. It is highly transparent to the luminous rays, which demonstrates the incompetency of its molecules to oscillate in the periods which excite vision. It is as highly opaque to the extra-red undulations, which proves the synchronism of its periods with those of the longer waves.

If, then, to the radiation from any source water shows itself to be eminently or perfectly opaque, it is a proof that the molecules whence the radiation emanates must oscillate in what may be called extra-red periods. Let us apply this test to the radiation from a flame of hydrogen. This flame consists mainly of incandescent aqueous vapour, the temperature of which, as calculated by Bunsen, is  $3259^{\circ}$  C., so that if transmission augments with temperature, we may expect the radiation from this flame to be copiously transmitted by the water. While, however, a layer of the bisulphide of carbon 0·07 of an inch in thickness transmits 72 per cent. of the incident radiation, and every other liquid examined transmits more or less of the heat, a layer of water of the above thickness is entirely opaque to the radiation from the flame. Thus we establish accord between the periods of the molecules of cold water and those of aqueous vapour at a temperature of  $3259^{\circ}$  C. But the periods of water have already been proved to be extra-red; hence those of the hydrogen flame

must be extra-red also. The absorption by *dry* air of the heat emitted by a platinum spiral raised to incandescence by electricity was found to be insensible, while that by the ordinary *undried* air was 6 per cent. Substituting for the platinum spiral a hydrogen flame, the absorption by dry air still remained insensible, while that of the undried air *rose to 20 per cent. of the entire radiation.* The temperature of the hydrogen flame was as stated, 3259° C., that of the aqueous vapour of the air was 20° C. Suppose, then, the temperature of our aqueous vapour to rise from 20° C. to 3259° C., we must conclude that the augmentation of temperature is applied to an increase of amplitude, and not to the introduction of periods of quicker recurrence into the radiation.

The part played by aqueous vapour in the economy of Nature is far more wonderful than hitherto supposed. To nourish the vegetation of the earth, the actinic and luminous rays of the sun must penetrate our atmosphere, and to such rays aqueous vapour is eminently transparent. The violet and the extra-violet rays pass through it with freedom. To protect vegetation from destructive chills, the terrestrial rays must be checked in their transit towards stellar space, and this is accomplished by the aqueous vapour diffused through the air. This substance is the great moderator of the earth's temperature, bringing its extremes into proximity, and obviating contrasts between day and night which would render life insupportable. But we can advance beyond this general statement now that we know the radiation from aqueous vapour is intercepted, in a special degree, by water, and reciprocally, the radiation from water by aqueous vapour; for it follows from this that the very act of nocturnal refrigeration which produces the condensation of aqueous vapour upon the surface of the earth—giving, as it were, a varnish of liquid water to that surface—imparts to terrestrial radiation that particular character which disqualifies it from passing through the earth's atmosphere and losing itself in space.

And here we come to a question in molecular physics which at the present moment occupies the attention of able and distinguished men. By allowing the violet and extra-violet rays of the spectrum to fall upon sulphate of quinine and other substances, Professor Stokes has changed the periods of those rays. Attempts have been made to produce a similar result at the other end of the spectrum—to convert the extra-red periods into periods competent to excite vision—but hitherto without success. Such a change of period the author believed occurs when a platinum wire is heated to whiteness by a hydrogen flame. In this common experiment there is an actual breaking-up of long periods into short ones—a true rendering of invisual periods visual. The change of refrangibility here effected differs from that of Professor Stokes, first, by its being in the opposite direction, that is from lower to higher; and secondly, in the circumstance that the platinum is heated by the collision of the molecules of aqueous vapour, and before their heat has assumed the *radiant form.*

But it cannot be doubted that the same effect would be produced by radiant heat of the same periods, provided the motion of the ether could be rendered sufficiently intense. The effect, in principle, is the same whether we consider the platinum wire to be struck by a particle of aqueous vapour oscillating at a certain rate, or by a particle of ether oscillating at the same rate.

By plunging a platinum wire into a hydrogen flame we cause it to glow, and thus introduce shorter periods into the radiation. These, as already stated, are in discord with water; hence we should infer that the transmission through water will be more copious when the wire is in the flame than when it is absent. Experiment proves this conclusion to be true. Water, from being opaque, opens a passage to 6 per cent. of the radiations from the flame and spiral. A thin plate of colourless glass, moreover, transmitted 58 per cent. of the radiation from the hydrogen flame; but when the flame and spiral were employed 78 per cent. of the heat was transmitted. For an alcohol flame Knoblauch and Melloni found glass to be less transparent than for the same flame with platinum spiral immersed in it; but Melloni afterwards showed that this result was not general, that black glass and black mica were decidedly more diathermic to the radiation from the pure flame. The reason of this is now obvious. Black mica and black glass owe their blackness to the carbon diffused through them. The carbon, as proved by Melloni, is in some measure transparent to the extra-red rays, and the author had in fact succeeded in transmitting between 40 and 50 per cent. of the radiation from a hydrogen flame through a layer of carbon sufficient to intercept the light of the most brilliant flames. The products of combustion of the alcohol flame are carbonic acid and aqueous vapour, the heat of which is almost wholly extra-red. For this radiation the carbon is in a considerable degree transparent, while for the radiation from the platinum spiral it is in a great measure opaque. By the introduction of the platinum wire, therefore, the transparency of the pure glass and the opacity of its carbon were simultaneously augmented; but the augmentation of opacity exceeded that of transparency, and a difference in favour of opacity remained.

No more striking or instructive illustration of the influence of coincidence could be adduced than that furnished by the radiation from a carbonic oxide flame. Here the product of combustion is carbonic acid; and on the radiation from this flame even the ordinary carbonic acid of the atmosphere exerts a powerful effect. A quantity of the gas, only one-thirtieth of an atmosphere in density, contained in a polished brass tube four feet long, intercepted 50 per cent. of the radiation from the carbonic oxide flame. For the heat emitted by solid sources, olefiant gas is an incomparably more powerful absorber than carbonic acid; in fact, for such heat the latter substance, with one exception, is the most feeble absorber to be found among the compound gases. For the radiation from the hydrogen flame, moreover, olefiant gas possesses twice the absorbent power of

carbonic acid; but for the radiation from the carbonic oxide flame at a common tension of one inch of mercury, while carbonic acid absorbs 50 per cent., olefiant gas absorbs only 24. Thus we establish the coincidence of period between carbonic acid at a temperature over  $3000^{\circ}$  C., the periods of oscillation of both the incandescent and the cold gas belonging to the extra-red portion of the spectrum.

It will be seen from the foregoing remarks and experiments how impossible it is to examine the effect of temperature on the transmission of heat, if different sources of heat be employed. Throughout such an examination the same oscillating atoms ought to be retained. The heating of a platinum spiral by an electric current enables us to do this while varying the temperature between the widest possible limits. Their comparative opacity to the extra-red rays shows the general accord of the oscillating periods of our series of vapours with those of the extra-red undulations; hence, by gradually heating a platinum wire from darkness up to whiteness, we gradually augment the discord between it and our vapours, and must therefore augment the transparency of the latter. Experiment entirely confirms this conclusion. Formic ether, for example, absorbs 45 per cent. of the radiation from a platinum spiral heated to barely visible redness; 32 per cent. of the radiation from the same spiral at a red heat; 26 per cent. of the radiation from a white-hot spiral, and only 21 per cent. when the spiral is brought near its point of fusion. Remarkable cases of inversion as to transparency occurred in these experiments. For barely visible redness formic ether is more opaque than sulphuric; for a bright red heat both are equally transparent, while for a white heat, and still more for a nearly fusing temperature, sulphuric ether is more opaque than formic. This result gives us a clear view of the relationship of the two substances to the luminiferous ether. As we introduce waves of shorter period, the sulphuric augments most rapidly in opacity; that is to say, its accord with the shorter waves is greater than that of the formic. Hence we may infer that the molecules of formic ether oscillate as a whole more slowly than those of sulphuric ether.

When the source of heat was a Leslie's cube filled with boiling water and coated with lampblack, the opacity of formic ether in comparison with sulphuric was very decided; with this source also the position of chloroform, as regards iodide of methyl, was inverted. For a white-hot spiral, the absorption of chloroform vapour being 10 per cent., that of iodide of methyl is 16; with the blackened cube as source, the absorption by chloroform is 22 per cent., while that by the iodide of methyl is only 19. This inversion is not the result of temperature merely; for when a platinum wire heated to the temperature of boiling water was employed as a source, the iodide was the most powerful absorbent. Numberless experiments, indeed, prove that from heated lampblack an emission takes place which synchronizes in an especial manner with chloroform. This may be thus illustrated. For the Leslie's cube coated with lampblack, the absorption by chloroform

is more than three times that by bisulphide of carbon ; for the radiation from the most luminous portion of a gas flame the absorption by chloroform is also considerably in excess of that by bisulphide of carbon ; while for the flame of a Bunsen's burner, from which the incandescent carbon particles are removed by the free admixture of air, the absorption by bisulphide of carbon is nearly twice that by chloroform ; the removal of the incandescent carbon particles more than doubled in this instance the relative transparency of the chloroform. Testing, moreover, the radiation from various parts of the same flame, it was found that for the blue base of the flame the bisulphide was the most opaque, while for all other portions of the flame the chloroform was most opaque. For the radiation from a very small gas flame, consisting of a blue base and a small white top, the bisulphide was also most opaque, and its opacity very decidedly exceeded that of the chloroform when the flame of bisulphide of carbon was employed as a source. Comparing the radiation from a Leslie's cube coated with isinglass with that from a similar cube coated with lampblack, at a common temperature of 100° C., it was found that out of eleven vapours all but one absorbed the radiation from the isinglass most powerfully ; the single exception was chloroform. It may be remarked that whenever, through a change of source, the position of a vapour as an absorber of radiant heat was altered, the position of the liquid from which the vapour was derived was changed in the same manner.

It is still a point of difference between eminent investigators as to whether radiant heat up to a temperature of 100° C. is monochromatic or not. Some affirm this, others deny it. A long series of experiments enables the author to state that probably no two substances at a temperature of 100° C. emit heat of the same quality. The heat emitted by isinglass, for example, is different from that emitted by lampblack, and the heat emitted by cloth or paper differs from both. It is also a subject of discussion whether rock-salt is equally diathermic to all kinds of calorific rays,—the differences affirmed to exist by one investigator being ascribed by others to differences of incidence from the various sources employed. MM. De la Provostaye and Desains maintain the former view, Melloni and M. Knoblauch maintain the latter. The question was examined by the author without changing anything but the temperature of the source. Its size, distance, and surroundings remained the same, and the experiments proved that rock-salt shared in some degree the defect of all other substances ; it is *not* perfectly diathermic, and it is more opaque to the radiation from a barely visible spiral than to that from a white-hot one.

The author devotes a section of his memoir to the relation of radiation to conduction. Defining radiation, internal as well as external, as the communication of motion from the vibrating molecules to the ether, he arrives by theoretic reasoning at the conclusion that the best radiators ought to prove the worst conductors. A broad consideration of the subject shows at once the general harmony of the conclusion with observed facts. Organic substances are all excellent radiators ; they are also extremely bad

conductors. The moment we pass from the metals to their compounds, we pass from a series of good conductors to bad ones, and from bad radiators to good ones. Water, among liquids, is probably the worst conductor; it is the best radiator. Silver, among solids, is the best conductor; it is the worst radiator. In the excellent researches of MM. De la Provostaye and Desains the author finds a striking illustration of what he regards as a natural law—that those molecules which transfer the greatest amount of motion to the ether, or, in other words, radiate most powerfully, are the least competent to communicate motion to each other, or, in other words, to conduct with facility.

II. "Remarks on Sun Spots." By BALFOUR STEWART, M.A., F.R.S.,  
Superintendent of the Kew Observatory. Received March 8,  
1864.

In the volume on Sun Spots which Carrington has recently published, we are furnished with a curve denoting the relative frequency of these phenomena from 1760 to the present time. This curve exhibits a maximum corresponding to 1788·6. Again, in Dalton's 'Meteorology' we have a list of auroræ observed at Kendal and Keswick from May 1786 to May 1793.

The observations at Kendal were made by Dalton himself, and those at Keswick by Crosthwaite. This list gives—

For the year 1787 . . . . .	27 auroræ,	For the year 1790 . . . . .	36 auroræ;
1788 . . . . .	53 ,,,	1791 . . . . .	37 ,,,
1789 . . . . .	45 ,,,	1792 . . . . .	23 ,,,

showing a maximum about the middle, or near the end of 1788. This corresponds very nearly with 1788·6, which we have seen is one of Carrington's dates of maximum sun spots.

The following observation is unconnected with the aurora borealis. In examining the sun pictures taken with the Kew Heliograph under the superintendence of Mr. De la Rue, it appears to be a nearly universal law that the faculae belonging to a spot appear to the left of that spot, the motion due to the sun's rotation being across the picture from left to right.

These pictures comprise a few taken in 1858, more in 1859, a few in 1861, and many more in 1862 and 1863, and they have been carefully examined by Mr. Beckley, of Kew Observatory, and myself. The following Table expresses the result obtained:—

Year.	No. of cases of facula to left of spot.	No. of cases of facula to right of spot.	No. of cases of facula equally on both sides of spot.	No. of cases of fa- culæ mostly be- tween two spots.
1858.....	2 .....	0 .....	0 .....	0
1859.....	18 .....	0 .....	0 .....	3
1861.....	9 .....	1 .....	3 .....	0
1862.....	64 .....	4 .....	7 .....	3
1863.....	47 .....	0 .....	9 .....	2
1864.....	18 .....	1 .....	2 .....,	1